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# Radar Investigations of Proposed Utilidor Sites at South Pole Station

Allan J. Delaney, Steven A. Arcone, and John H. Rand

August 1999

DTIC QUALITY INSPECTED 4

19990823 124

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profiles, 366 m long, were recorded along the proposed W-E sewer line route. Additional S-N profiles were recorded on the W-E route to delineate a particularly intense reflection. The profiles show that both proposed corridors contain many large and small buried items. Multiple targets at depths of 3.0 to 4.9 m occur along the S-N line. Along the W-E lines, there are multiple targets at similar depths. A particular area is densely cluttered and large targets appear on multiple parallel lines. Near the dome isolated targets appear at depths as great as 7.6 m.

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# Special Report 99-10



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Prepared for  
**NATIONAL SCIENCE FOUNDATION**

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## PREFACE

This report was prepared by Allan J. Delaney, Physical Science Technician, Dr. Steven A. Arcone, Geophysicist, Snow and Ice Division, and John H. Rand, General Engineer (Polar), U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this work was provided by the National Science Foundation.

This work was technically reviewed by George Blaisdell and Paige Peapples, both of CRREL.

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## Radar Investigations of Proposed Utilidor Sites at South Pole Station

ALLAN J. DELANEY, STEVEN A. ARCONE, AND JOHN H. RAND

### INTRODUCTION

Ground-penetrating radar (GPR) is an excellent planning tool for use in the cold-snow environment of Antarctica, where propagation conditions for GPR pulses are nearly ideal. GPR is commonly used to profile subsurface stratigraphic horizons and to detect local objects. In Antarctica, near-surface snow layers reflect only a small portion of the radar signals, and the relative absence of liquid water results in very little signal loss (attenuation). In such a cold, low-attenuation environment, detection of buried targets is made possible primarily by the contrast between the dielectric permittivities of air, dense snow (firm), and buried debris. Also, there is little signal interference (electrical noise) in the Antarctic. These conditions allow use of a GPR system that consists of a low power, broadband transmitter, and a very high gain receiver. The system can detect closely spaced layers (high resolution) and it can easily detect metal, lumber, and other debris buried in snow.

Earlier, in Antarctica, CRREL proved the feasibility of crevasse detection from helicopters by determining the effect of air speed, altitude, and radar scan rate on data quality (Delaney and Arcone 1995). Profiles were also recorded on the snow surface directly over snow-bridged crevasses, providing direct correlation between the voids and the radar signatures. Recently, in Alaska, CRREL successfully used GPR to produce maps that guided excavation of buried hazardous waste and munitions (Delaney et al. 1997).

Here, we discuss a survey conducted at South Pole Station in November 1997 to locate buried

debris that could impede tunnel excavation. GPR profiles were recorded directly along transects above proposed tunnels to be used as future utilidors. The GPR antennas transmitted pulses centered near 900 and 400 MHz to provide near-surface detail, to depths of 4.1 and 15.0 m, respectively.

### METHODS

#### Ground Penetrating Radar (GPR)

The GPR system consisted of a digital control unit and transducer (Fig. 1), manufactured by Geophysical Survey Systems Incorporated (GSSI) of North Salem, New Hampshire. The control unit triggers pulses at a selected repetition rate (50 kHz for these investigations). The received



Figure 1. GSSI ground-penetrating radar system, video display, 400-MHz transducer, and cables.

signals are sampled in progressive time steps and converted to audio frequencies for display and storage. Completed data scans were recorded in digital format at a rate of 48 per second. Scans are displayed using a selected time-range that determines pulse penetration depth. A selected range-gain suppresses the higher amplitude early returns and enhances the lower amplitude later returns reflected from layer interfaces and material transitions.

The antennas were 400- and 900-MHz (center frequency) shielded dipole pairs, radiating pulses of 6- and 2.8-ns duration, respectively. The antenna terminals connect directly to the transmitter and receiver electronics and the entire units are referred to as a transducer. When using the 400-MHz transducer, we recorded signals for a time range of 150 ns. To search for horizons very near the surface, profiles were recorded with the 900-MHz transducer at a time range of 40 ns. The transducers were towed simultaneously with a tracked vehicle (Fig. 2) at a survey speed of

est. Reflections can also originate from continuous snow horizons compacted by vehicle traffic and wind.

The profiles show distance as the horizontal axis and the two-way travel time  $t$  as the vertical axis. Travel time  $t$  is converted to depth  $d$  using the equation

$$d = ct/2\sqrt{\epsilon}$$

where  $c = 30 \text{ cm/ns}$ , the speed of radio waves in a vacuum, and  $\epsilon$  is the snow dielectric permittivity. The factor of 2 accounts for the round trip pulse propagation path, to and from the reflecting surface. The dielectric permittivity of cold snow was determined from the time-distance slope of hyperbolic diffraction asymptotes. The mean value of  $\epsilon = 1.7$  measured from the many diffractions and used for depth calibration is in agreement with values previously determined at South Pole (Arcone et. al. 1995). Depth calibration is highly accurate in this cold snow environment. The selected time-range settings for the 400- and 900-

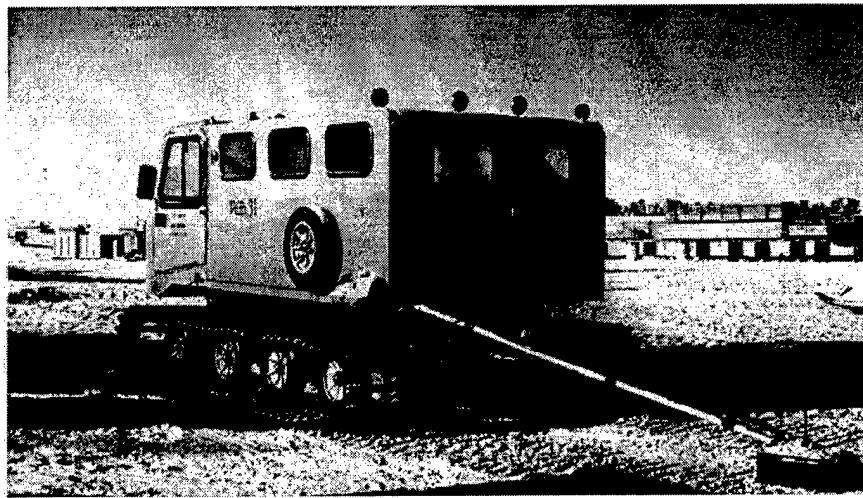


Figure 2. 400-MHz transducer mounted for towing on the snow surface.

approximately 1 m/s. Close antenna contact with the surface facilitated signal transmission into the snow. The data were filtered to remove noise and horizontally scaled between event markers to compensate for towing speed irregularities.

Events within a GPR profile consist of bands of reflections from continuous horizons and discrete hyperbolic diffractions that can originate from individual targets and abrupt material transitions. Target depth is calculated from the time delay to the hyperbola apex when the dielectric permittivity  $\epsilon$  of the subsurface is known. Clusters of diffractions often indicate a target of inter-

MHz signals are equivalent to 15.0 and 4.1 m, respectively. The longer time range was selected to provide penetration deeper than the snow surface that existed at the time of dome construction. The shorter time range was used to delineate near-surface horizons and cables. The floor level of the planned tunnels are anticipated to be 6.1 m below the existing snow surface.

#### Transect selection and location

The radar was operated from within the cab of a small tracked vehicle. The antennas were towed, in tandem, approximately 4 m behind the

vehicle. Profile data at both frequencies were recorded simultaneously on two channels, which contributed to an efficient survey and allowed a direct profile comparison for the same transects. The proposed tunnel centerlines were located and flagged by ASA surveyors and are shown (Fig. 3) in relation to prominent South Pole Station features. Transects were spaced from 1.2 to 6.1 m apart on both sides of the centerlines, along the two survey areas, to provide complete survey coverage with overlapping antenna patterns. As the beamwidth of the GSSI transducers is approximately  $100^\circ$  across the transects, in cold, low-permittivity snow, targets appearing at any depth within the selected radar time range could be detected on multiple lines. The approach assured complete coverage of the survey area.

Eight transects were recorded along the proposed S-N water-well tunnel route, starting at -500 ft (-152.4 m) and extending to 1200 ft (365.8 m). Twelve transects were recorded along the proposed W-E sewer tunnel route, starting at -700 ft (-243.8 m) and extending to -2000 ft (-609.6 m). Additional short W-E transects, recorded between -500 ft (-152.4 m) and -700 ft (-213.4 m), were compromised by the proximity and movement of large construction equipment. In several areas the proposed routes pass close to buried towers, sloping guy cables, power cables, and fuel lines. Radar reflections from these near-surface targets, especially numerous along the S-N route north of the fuel line, are discussed below. The station numbering corresponds to survey locations provided by ASA.

The planned sewer utilidor centerline extends -1500 ft (-457 m) east from the southern end of the water-well utilidor. It passes near the existing water well at -1000 ft (-305 m) and ends near the antenna farm at -2000 ft (-610 m). Excavation of snow to relocate the mechanical arch, and stationary equipment, prohibited data collection between -500 ft (-152 m) and -700 ft (-213 m) during the November 1997 survey. Therefore, most transects extended east from -800 ft (-244 m). Between -800 ft (-244 m) and -1050 ft (-320 m), all transects are confined by existing buildings and stored material to the narrow, traveled snow corridor south of the water well. East of -1150 ft (-351 m), transects separate and are parallel with the surveyed centerline. Two transects were profiled south of the centerline at 1.2 and 4.0 m. Ten additional transects were profiled north of the centerline at 1.2, 4.0, 6.1, 12.0, 15.2, 18.3, 21.3, 24.3, 34.7, and 39.3 m. The area north of center-

line, having been little used because of proximity to the radio antennas, is the most probable site for future sewer expansion.

## RESULTS

### South-north survey

The S-N tunnel centerline is parallel to and 37.2 m west of the existing fuel arch centerline. The tunnel would service future water wells. Transects extend north from the centerline of the planned E-W utilidor at -500 ft (-152.4 m), intersect the surface fuel line at 350 ft (106.7 m), and extend past partially buried, vertical steel-towers before ending at 1200 ft (365.8 m). Radar profiles were recorded along four transects both east and west of the centerline. Transects east of centerline were located at 1, 2, 3, and 5 m. Transects west of centerline transects were located at the same intervals. Because of scale, only centerlines are shown on Figure 3.

A 700-ft (213-m) segment of the 400-MHz radar profile (2 m east of the S-N centerline) is shown in Figure 4. Horizontal event marks correspond with the ASA surveyed stations. The distance between marks is 100 ft (30.5 m). The sloping, near horizontal bands represent pulse reflections from snow horizons compacted by vehicle traffic. Of particular interest is the lowest compaction

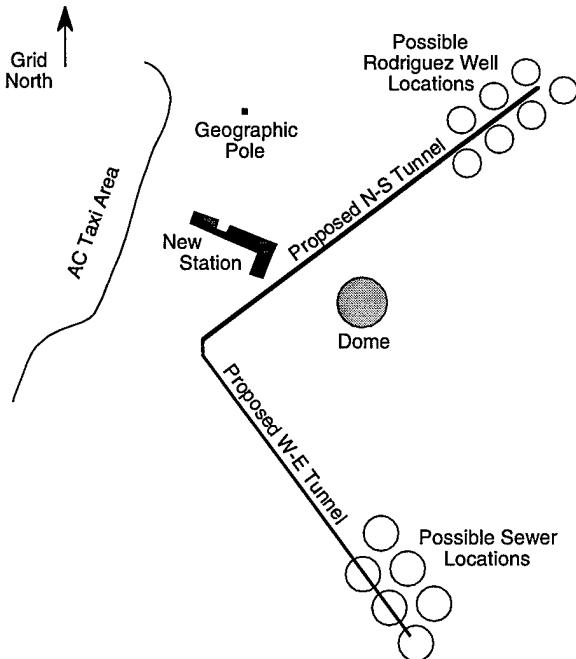
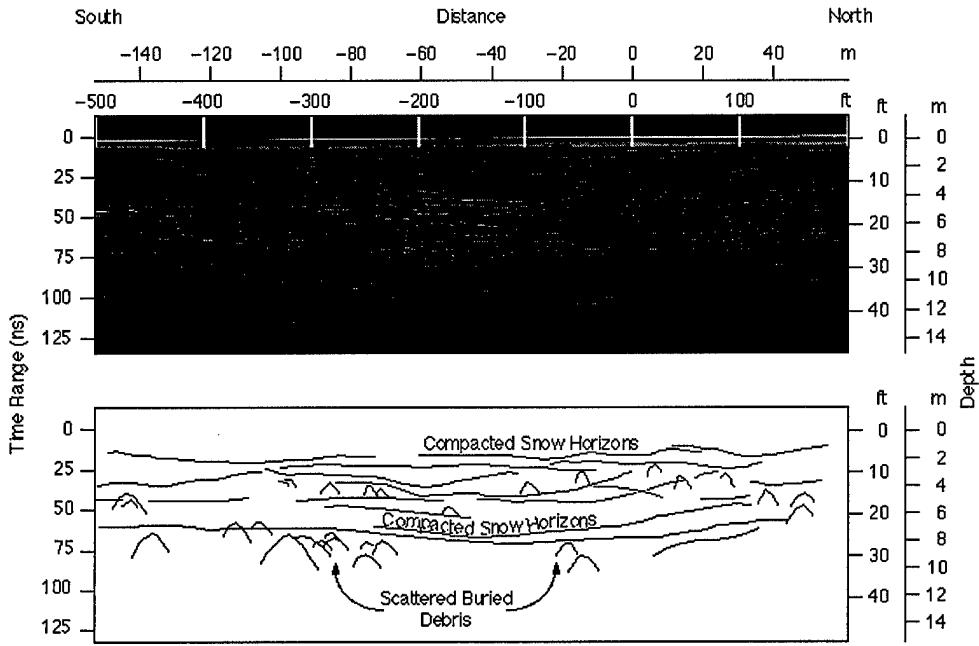


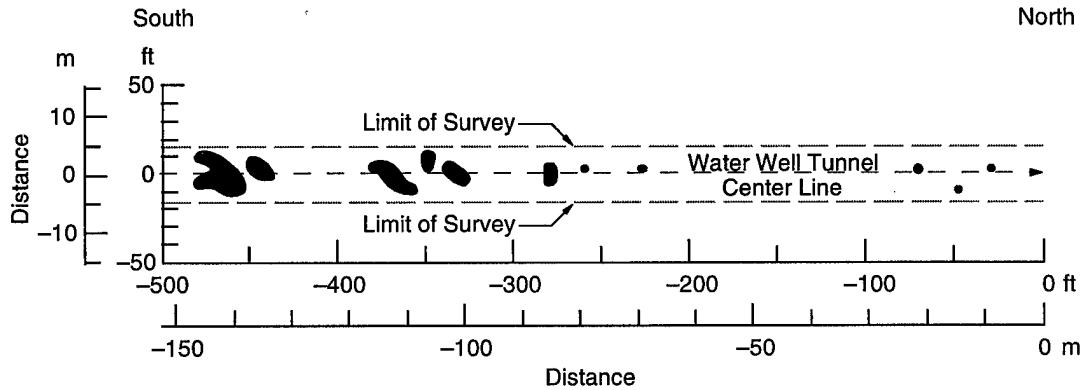
Figure 3. South Pole Station and the centerlines of the two proposed tunnels.



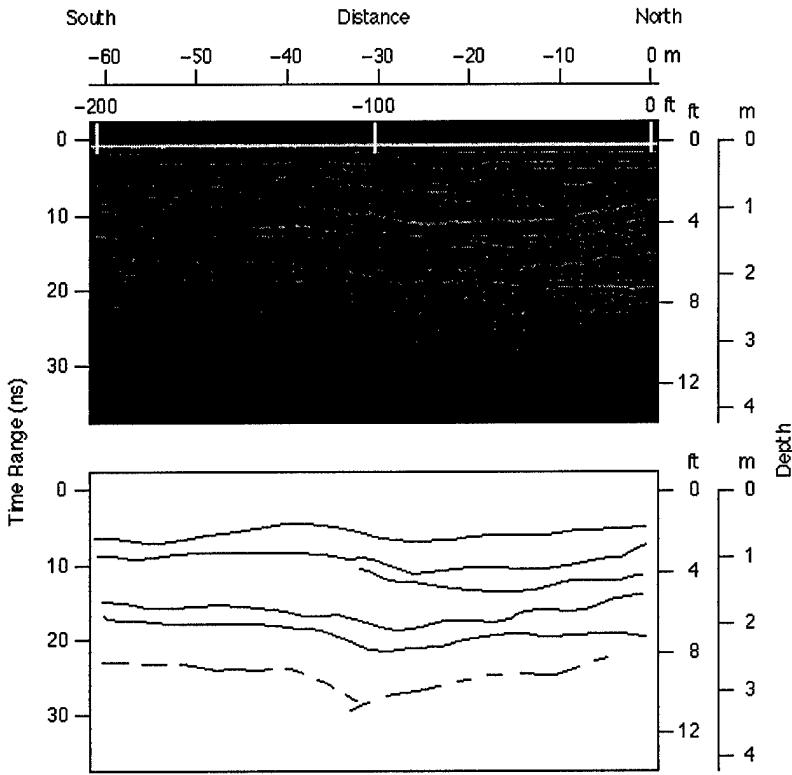
*Figure 4.* 400-MHz profile segment (top) recorded from -500 ft (-152 m) to 300 ft (91 m) along the S-N tunnel route (transect 5) and interpretation (bottom). Near-horizontal reflections originate from compacted snow horizons. All of the diffractions (hyperbolic reflections) indicate buried debris. The depth of burial is shown on the right, vertical axis.

horizon, whose deepest point appears at 74 ns, corresponding to a depth of 28 ft (8.5 m) below the existing snow surface. This reflection probably represents the 1970 snow surface, which was compacted during dome construction. A second feature of interest is the many hyperbolic diffractions that appear throughout the record, at and above the 1970 surface. These reflections represent debris buried within the snow. Many hyperbolas are grouped together and others coincide with intermediate snow horizons, further confirming their origin. The apexes of all hyperbolas range from 3 to 8 m below the existing snow surface and many of the targets can be grouped.

All eight S-N profiles were examined for the appearance of hyperbolas and a location map was created (Fig. 5). Closely spaced targets are represented as a continuous area because the wide antenna beamwidth precludes discrimination between a large target and several closely spaced, smaller targets. Although the exact shape and horizontal extent of buried debris is difficult to estimate from a preliminary survey such as this, depth to the debris is highly accurate. The range of depths to the buried debris is also given. The amplitude of the signals reflected must also be considered in interpretation. Low-amplitude hyperbolas suggest linear, metallic cables at depths



*Figure 5.* Contour location and depth to the largest debris mapped on the S-N tunnel route.



*Figure 6. 900-MHz profile segment (top) recorded between -200 ft (-61 m) and 0 ft (0 m) along the S-N tunnel route and interpretation (bottom). The shorter radar time-range (40 ns) used to delineate near-surface snow horizons did not provide enough signal penetration to detect the deeper targets. The irregular near-horizontal horizons were not detected with the coarser resolution 400-MHz transducer.*

of 3 m at -360 ft (-110 m) and -280 ft (-85 m). High-amplitude hyperbolas, particularly those at -470 ft (-143 m) and -370 ft (-113 m), suggest large, irregular debris, 3 m or more across. Additional hyperbolas, scattered throughout the survey area, originate from smaller isolated debris.

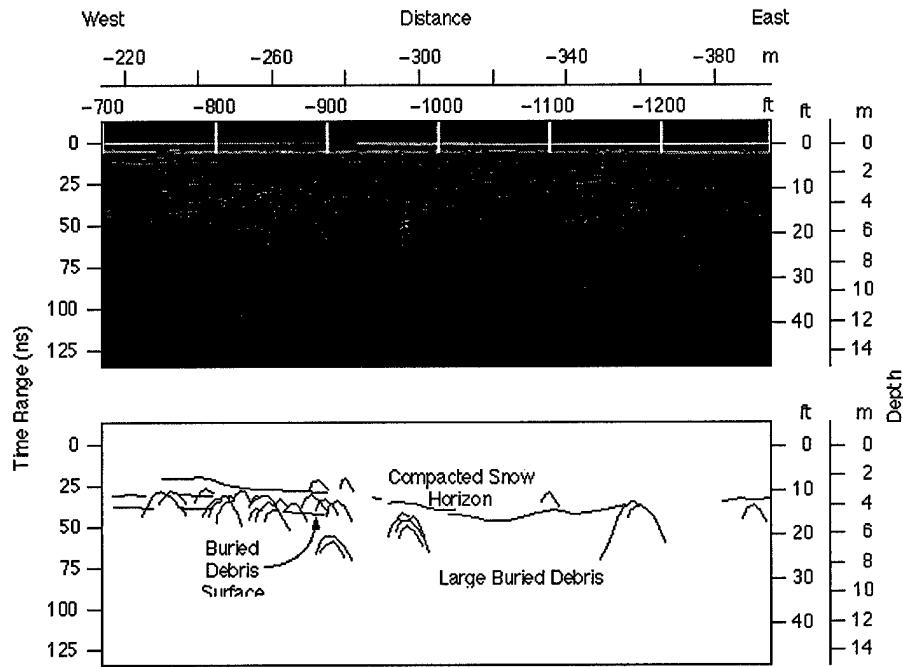
The profile segment in Figure 4 ends approximately 6.1 m south of the surface fuel line that extends from the arch to the aircraft-staging area. North of the fuel line, from 320 ft (98 m) to 1200 ft (366 m), horizontal compaction horizons are absent (there is little vehicular traffic in this area), and high-amplitude hyperbolas are isolated. At 400 ft (122 m), 600 ft (183 m), and 680 ft (207 m), large hyperbolas appear at depths of 8.5, 4.9, and 4 m, respectively. From 800 ft (244 m) to 1000 ft (305 m), there are many scattered hyperbolas that originate from a nearly buried steel tower and its support cables. These extraneous diffractions, from off-axis targets, are unavoidable in low-permittivity snow when using a wide-beam-width antenna.

The 900-MHz profiles were recorded coinci-

dent with all 400-MHz profiles. The time-range selected, 40 ns, provided a detailed record of the top 4 m. The pulse-width at 900 MHz is very short (2.8 ns), making the transducer well suited for distinguishing closely spaced, near-surface horizons. Figure 6 shows a segment of 900-MHz data recorded along S-N transect 2 (in front of the dome). All of the irregular horizons originate from compacted snow layers. No hyperbolic reflections were seen in this upper section. Elsewhere in the survey, the 900-MHz transducer detected communication and power cables that were very near the surface and not detected with the 400-MHz transducer.

#### West-east survey

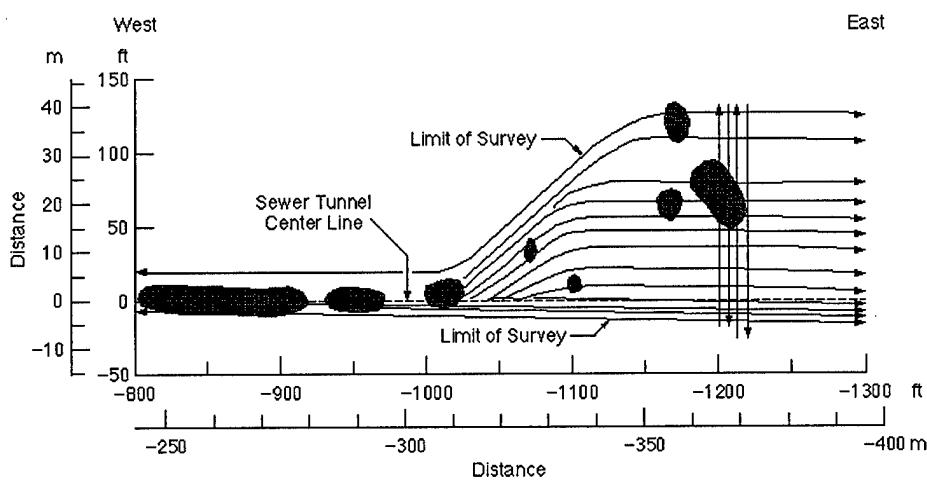
A 600-ft (183-m) segment of the 400-MHz radar profile recorded along transect 21 is shown in Figure 7. As in the S-N profile, reflections are seen that correspond to compacted snow horizons. More conspicuous, however, are the intense clustered and single hyperbolas that occur near -850 ft (-259 m), -970 ft (-296 m) and -1180 ft



*Figure 7.* 400-MHz profile segment (top) recorded from -700 ft (-213 m) to -1300 ft (-396 m) along the W-E sewer tunnel route (transect 22) and interpretation (bottom). The event marks are spaced at 100-ft (31-m) intervals and the radar time-range provides 15 m of penetration. The sloping reflections represent a compacted snow surface. The diffractions indicate buried debris. The continuous zone of diffractions between -800 ft (-244 m) and -900 ft (-274 m) is interpreted as a debris horizon. The intense and overlapping diffractions at -970 ft (-296 m) and the intense diffraction at -1180 ft (-360 m) are interpreted to represent large buried debris.

(-360 m) at depths of 3.7, 5.1, and 4.2 m, respectively. The first anomaly extends from -800 ft (-244 m) to -900 ft (-274 m) and appears to represent a buried debris surface. The overlapping hyperbolas, centered at -850 ft (-259 m), are particularly intense, and the shape traced by their

apexes suggests a large, irregular object. The hyperbola at -970 ft (-296 m) is also intense and appears just below the sloping compaction surface. The reflection at -1180 ft (-360 m) also appears as a confined object. However, it is more significant because similar reflections appear on



*Figure 8.* Transect locations between -800 ft (-244 m) and -1300 ft (-396 m) along the west-east route. The closed contours locate the largest debris.

three parallel profiles and it was further confirmed on four additional N-S profiles. East of ~1400 ft (~427 m), no hyperbolas and no deeper horizontal layering were seen in all of the radar profiles. The extent and depth of burial are summarized by Figure 8.

## CONCLUSIONS AND RECOMMENDATIONS

These radar surveys indicate that portions of both the proposed S-N and W-E tunnel routes are contaminated with significant amounts of buried debris. The debris exists primarily at depths from 10 ft (3 m) to 26 ft (8 m) and is concentrated in areas that receive heavy vehicle traffic. The sewer-tunnel route profiles indicate three areas where large items are buried; all are located along the corridor that runs past the existing water well. The water-well tunnel route profiles indicate both large and small debris scattered throughout the snow section southwest of the dome entrance. The water-well segment that extends into the "clean-air" area appears generally free from debris; however, interpretation is complicated by reflections from abandoned steel towers and their supporting cables. The sewer-tunnel segment that extends into the antenna area is free from buried debris. With the exception of one isolated reflec-

tion at a depth of 28 ft (8.5 m), both proposed routes are free of buried debris *below* the snow horizon compacted by the 1970 dome construction.

The extent and amplitude of the hyperbolas detected indicate debris that could greatly impede or halt tunnel construction. We recommend either re-routing the proposed tunnels in areas of heavy contamination or constructing the tunnels below the 1970 snow surface.

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# REPORT DOCUMENTATION PAGE

*Form Approved  
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Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestion for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED	
	August 1999		
4. TITLE AND SUBTITLE  Radar Investigations of Proposed Utilidor Sites at South Pole Station			5. FUNDING NUMBERS
6. AUTHORS  Allan J. Delaney, Steven A. Arcone, and John H. Rand			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  U.S. Army Cold Regions Research and Engineering Laboratory 72 Lyme Road Hanover, New Hampshire 03755-1290			8. PERFORMING ORGANIZATION REPORT NUMBER  Special Report 99-10
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Science Foundation Arlington, Virginia 22230			10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES     For conversion of SI units to non-SI units of measurement consult <i>Standard Practice for Use of the International System of Units (SI)</i> , ASTM Standard E380-93, published by the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pa. 19428-2959.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited.  Available from NTIS, Springfield, Virginia 22161.		12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  At South Pole Station, ground penetrating radar profiles were recorded along the surveyed S-N and W-E routes of two proposed snow tunnels that would function as future water and sewer utilidors. The radar system was operated from within the cab of a tracked vehicle that towed two antennas in a sled. The two antennas transmitted pulses centered near 900 and 400 MHz to provide near-surface detail to penetration depths of 4.1 and 15.0 m, respectively. Eight longitudinal profiles, 518 m long, were recorded along the proposed S-N water line route, and 12 longitudinal profiles, 366 m long, were recorded along the proposed W-E sewer line route. Additional S-N profiles were recorded on the W-E route to delineate a particularly intense reflection. The profiles show that both proposed corridors contain many large and small buried items. Multiple targets at depths of 3.0 to 4.9 m occur along the S-N line. Along the W-E lines, there are multiple targets at similar depths. A particular area is densely cluttered and large targets appear on multiple parallel lines. Near the dome isolated targets appear at depths as great as 7.6 m.			
14. SUBJECT TERMS Buried debris Ground penetrating radar Snow tunnels			15. NUMBER OF PAGES 10
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT  UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE  UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT  UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL